ON THE PRODUCTION OF AN ARTIFICAL HISS.

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(*Read November 6, 1914.*)

In *Nature* of May 29, 1913, Lord Rayleigh asked to be told "how to make an artificial hiss." I replied that, if Köhler's observations are reliable, "a Galton whistle, set for a tone of 8,400 v. d., will give a pure *s*."[1] Lord Rayleigh, however, was not impressed by the suggestion.[2]

It occurred to me that the question might be put to the test of experiment. The sound of a Galton whistle set for 8,400 v. d. might be imitated by the mouth, and a series of observations might be taken upon material composed partly of the natural (mouth) sounds and partly of the artificial (whistle) tones. If a listening observer were unable to distinguish between the two stimuli, and if the mouth-sound were shown, phonetically, to be a true hiss, then it would be proved that the whistle also gives an *s*, and Lord Rayleigh would be answered.

The experiment was more troublesome that I had anticipated; but I may say at once that it has been carried out, and with affirmative result.

We used an Edelmann-Galton whistle (No. 423) actuated by a rubber bulb.[3] Our first difficulty was to find a competent experimenter. For the sound of the whistle is clean-cut, uniform, so to say dogmatic. This very definite stimulus has to be duplicated by a certain setting of tongue and lips, and by voluntary regulation and

[1] *Nature*, July 3, 1913; W. Köhler, *Zeits. f. Psych.*, LXIV., 1913, 93.

[2] *Nature*, July 31, 1913.

[3] The bulb that comes with the instrument must soon be renewed. It may be worth while to point out that bulbs of white or grey sulphur-coated rubber should never be employed; the fine dust chokes the mouthpiece and plays havoc, *e. g.*, with terminal determinations. We use a black rubber that is slightly more flaccid than that furnished by Edelmann.

direction of a current of air. But not only are there gross differences in the mode of formation of the *s*-sound; there are also individual differences, due apparently to the arrangement of the teeth, the shape and size of the tongue, and so forth;[4] and beside these, there are differences in ability to maintain the sound begun, to hold it from fluctuation during its course. The sound that one emits, on first trying to imitate the whistle, may therefore be almost comically wrong,—broad, harsh, irregular, soft, wavery, instead of sharp and keen.

We presently found two experimenters, Mr. N. P. Stephens and Mr. P. T. Carson, who after practice were able in a large proportion of successive attempts to reproduce the sound of the whistle. Neither these nor the other volunteers whom we tried out could, however, imitate the sound obtained by the ordinary vigorous squeeze of the bulb, such a squeeze as one gives in determinations of the terminus. We therefore had recourse to a compression which, though sharp and definite, was still weaker than that by which the whistle is usually actuated. The difference between the mouth-sound and the whistle-sound given at full intensity is, so far as our observations go, that the latter is beady, intense, compact, while the former is broader, weaker, coarser. The compression which we used was, nevertheless, strong enough to yield clear dust-figures by the Kundt method.[5] No doubt, it varied somewhat, both in the experimental series and in the dust-figure determinations. But the hand-pressure becomes rather surprisingly even, with a little practice; and determinations made at different times by Dr. Foster varied only between the limits of 8,594 ± 63 v. d. and 8,522 ± 27 v. d. It is therefore certain that we were working in the near neighborhood of Köhler's optimal 8,400 v. d.

[4] See, *e. g.*, C. L. Merkel, "Physiologie der menschlichen Sprache," 1866, 186 ff., Taf. III.; G. H. von Meyer, "The Organs of Speech," 1884, 314f.; G. E. Sievers, "Grundzüge der Phonetik," 1885, 56 ff., 122 f.; O. Jespersen, "The Articulations of Speech Sounds," etc., 1889, 61 f., 87; H. Hoffmann, "Die Lautwissenschaft," etc., 1901, 62; W. Vietor, "Elemente der Phonetik," etc., 1887, 125 ff.; E. Seelmann, "Die Aussprache des Latein," etc., 1885, 245 f.; H. Sweet, "A Handbook of Phonetics," 1877, 33, 39 f.

[5] M. T. Edelmann, "Studien über die Erzeugung sehr hoher Töne, etc.," Drude's *Annalen*, II. [CCCVII.], 1900, 469 ff.

An ideal experimental series would now have consisted of equal numbers of mouth-sounds and whistle-sounds arranged in haphazard order. But the experimenters could not thus accurately reproduce the whistle-sound. If the series chanced to call for several mouth-sounds in succession, then the setting of the mouth could be maintained; but if mouth and whistle alternated, or if a single mouth-sound were to be given among several whistle-sounds, there was need of readjustment and possibility of initial failure. It seemed best that whenever the mouth-sound was obviously wrong, and when (as sometimes happened) the squeeze of the bulb was too light or too heavy, the experimenter should say: "Don't count that! Repeat!" and should simply try again. This procedure gave the observers a certain advantage; but we thought it preferable to a voluntary change or a further haphazard determination of the stimulus. The more successful of our two experimenters, Mr. Stephens, was obliged, even at his highest level of practice, to repeat the mouth-sound in 12 to 15 per cent. of the trials.

There was a further complication. The observers sat at a distance of not more than 1 m. from the source of sound; they declared that, if they were to judge discriminatingly, they must be as near as possible; and they tended to lean or move in toward the experimenter. The preliminary experiments showed that, under these conditions, their judgment might be influenced by secondary indications—the direction of the sound, the noise of breathing, of setting the mouth, even of the squeeze of the bulb, the noise of preparatory movements in general. Hence they were informed before the regular series began that these indications were not to be relied upon, but that the experimenter might in any given test make misleading preparations. In fact, 50 per cent. of the mouth-sounds were accompanied by noises of bulb and table, and 75 per cent. of the whistle-sounds by noises of breathing and mouth-setting. The numerical results and the introspective reports prove that this ruse was successful. The observers based their discriminations, for the most part, upon the temporal course and the "size" of the stimuli; the sound was judged to be "whistle" if it was hard, clear-cut, abrupt, and to be "mouth" if it was fluctuating, "trembly," soft, diffuse. Sometimes pitch was referred to (whistle higher), and sometimes

intensity (whistle louder). The number of confusions testifies that these differences were not very dependable.

The first series of experiments (July, 1914; Mr. Stephens, experimenter; Miss F. A. Bean, observer) consisted, as planned, of 70 mouth-sounds and 70 whistle-sounds taken in haphazard order. Aside from the disturbances to which I have referred, the results were:

	Whistle.	Mouth.
Whistle judged as	60	10
Mouth judged as	25	45

Mr. Stephens was at this date relatively unpractised, while Miss Bean had had extended practice in the discrimination of whistle-tones. The number of confusions (25 per cent. of the whole number of observations) was, evidently, large enough to warrant a continuation of the experiment.

Other series, made by Messrs. Stephens and Carson with other observers, brought results of the same numerical order; they need not be cited. I pass at once to the two final series made (August, 1914) by Mr. Stephens. The first comprised two part-series of 50 tests, each composed of 25 mouth-sounds and 25 whistle-sounds. The observer, Dr. W. S. Foster, knew the plan of the investigation, had himself tried to reproduce the whistle-tone by mouth, and had had recent and unusually extended practice in the discrimination of whistle-tones. The percentages of confusion were:

Whistle judged as mouth	18
Mouth judged as whistle	20

or an average confusion of 19 per cent.

In the second series, two part-series of 50 tests were composed, the one of 22 whistle and 28 mouth sounds, the other of 28 whistle and 22 mouth sounds. The observers, Dr. E. G. Boring, Dr. L. D. Boring and Dr. M. E. Goudge, sat together for the experiment. Dr. E. G. Boring had had a good deal of practice with the whistle, and the other observers had performed the regular laboratory experiments in which it is employed. All three were, however, given special practice (with knowledge) in the discrimination of the stimuli now to be used. The percentages of confusion were:

Observer.	Whistle Judged as Mouth.	Mouth Judged as Whistle.
E. G. B.	20	36
L. D. B.	45	38
M. E. G.	35	39

or an average confusion of 35.5 per cent.

There is, naturally, a tendency, on the part of the practised observers, to judge "mouth as whistle" more often than "whistle as mouth": the percentages are, for Miss Bean, 35.7 : 14.3, and for Dr. E. G. Boring, 36 : 20. Dr. Foster, who can hardly be deceived, gives approximately equal percentages of confusion; but in his case too the ratio 20 : 18 favors "mouth as whistle." The less practised observers, however, offset each other. I had expected a far greater preponderance of correct judgments of the whistle, *i. e.*, a lesser number of judgments of "whistle as mouth"; and I think that the percentages actually obtained speak well for the skill of the experimenter.

It remains to show that our mouth-sound was a hiss. Neither of the experimenters was versed in phonetics; but we asked them to observe and describe carefully the position of lips and tongue during imitation of the whistle-sound. Mr. Stephens writes:

"The position of the tongue is substantially, so far as I can judge, the same as that in which we produce the sound of the letter *s-s-s*. The sides of the tongue are so curled up that they rest against the inside of the upper teeth, on the sides. The middle of the tongue thus of course forms a hollow, up to the tip,—which very nearly touches the roof of the upper jaw just about a quarter-inch above the upper teeth . . . . For the production of a light hiss which is not to be heard loudly the tongue-muscles are semi-tightened as also are the muscles of the jaw and throat. The thin column of air which is forced lightly between the tip of the tongue and the point on the roof of the mouth makes production of sound. Teeth along sides and back are possibly 5 or 6 mm. apart, thus leaving plenty of opening for ejection of air. The lips stand a quarter-inch apart, with little or no drawing at the corners, for the light hiss. Lips, in the production of this sound, play little or no part; they merely are separated sufficiently so as not to interfere with air and sound. Unless they are well apart, however, they do interfere with the intensity and seeming pitch of the hiss."

This is a very fair amateur account of the production of a hiss; and if it is compared with the formula given, *e. g.*, by Jepersen, we

cannot doubt that Mr. Stephens was sounding an English *s*.[6] At the point where I have marked an omission, he draws a diagram which, with allowance made for amateur draughtmanship, is identical with the "[s] nach Bremer" of Jespersen's plate; it is needless to say that he had never opened Jespersen's book. Mr. Carson gives a very similar account, except that he appears to place the tip of his tongue a trifle further forward, and thus to approximate the German *s*. It is quite clear, then, that the experimenters were hissing.

So we have the artificial hiss that Lord Rayleigh asked for. It may be too weak for his purposes; and, more especially, it may be of too brief duration. We were able, however, to match the abrupt hiss of the experiments to a continuative hiss sounded by a second Edelmann whistle (No. 679) connected with the Whipple tanks: intensively, the match was only approximate; qualitatively, we regard it as fairly accurate.

For the qualitative determination we employed two methods. (1) The sound of whistle No. 423, actuated as in the experiments, was compared with three sounds from whistle No. 679 actuated by a regulated current of air from the tanks. These three sounds lay at what we supposed to be the point of equality with the sound of No. 423, at a pitch some 400 v. d. higher, and at a pitch some 400 v. d. lower. The three comparative pitches were intermixed in haphazard order; both time-orders were presented; and for the final series of observations we had the services of Professor H. P. Weld, a skilled musician as well as psychologist. (2) By a roundabout method of determination, which involved reliance on the Edelmann tables, we established the "identical" pitch of No. 679 as 8,430 v. d. Since Professor Weld's judgment made this pitch equal to or very slightly lower than the given pitch of No. 423, and since the error of our determination (provided always that Edelmann's tables are correct) can hardly have exceeded ± 100 v. d., we may assume that the two whistles gave very nearly the same *s*.

[6] O. Jespersen, "Lehrbuch der Phonetik," 1904, 34, 127 f. Mr. Stephens' use of the word "hiss" was spontaneous, not due to suggestion.

We were unable to determine the pitch of the continuative hiss by the Kundt dust-method; the lycopodium powder obstinately refused to move.

The accuracy of the Edelmann tables has been questioned by C. S. Myers ("On the Pitch of Galton Whistles," *Journ. of Physiol.*, XXVIII., 1902, 417 ff.). Edelmann does not give the m. v. of his scale readings; but it is possible that his technique is so accurate that the variation is minimal, or even that a single count suffices. Neither does he tell us how he compresses his bulb; it is probable that he uses some mechanical device which ensures a constant compression. We have ourselves made the following determinations with whistle No. 423 (temperature read as the mean of four thermometers):

(1) Ordinary vigorous squeeze, such as is employed in terminal determinations:

Found from 5 trials with the dust-method..... 8,897 ± 18 v. d.

By Edelmann's table..... 8,775

(2) Weaker squeeze, used in our experiments:

Found by dust-method..... 8,594 ± 63 v. d. to 8,522 ± 27 v. d.

By Edelmann's tables + judgments of coincidence of tones 8,430

(3) Very violent squeeze, 10 trials by dust-method..... 9,046 ± 71 v. d.

It is clear that Edelmann uses a "normal" compression, of the same order as that which an experimenter naturally employs for terminal tests. Random determinations of our two whistles at different points of the scale, with the ordinary vigorous squeeze, agree within about 100 v. d. with the Edelmann tables.

We have had but little experience with continuous tones under change of water-pressure; but we find, so far, that the pitch of our whistles does not alter appreciably within the limits of 90 to 160 mm. of pressure.

While, then, we do not question the accuracy of Myers' determinations, we think that there is no need either to doubt the reliability of the Edelmann whistle under "normal" conditions.